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Fall growth, nutritive value, and estimation of total digestible nutrients for cereal-grain forages in the north-central United States[1]

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ABSTRACT: Throughout the Southern Great Plains, wheat is managed frequently as a dual-purpose crop, but this production paradigm is not necessarily applicable throughout other regions of the United States, and a wider array of management options can be considered for forage-only uses of cereal grains. Our objectives were to assess the fall-growth potential of wheat (*Triticum aestivum* L.), triticale (X *Triticosecale* Wittmack), and oat (*Avena sativa* L.) cultivars in Wisconsin, and then to further evaluate and compare the fiber composition and TDN of these fall-grown forages. For 2006, yields of DM for all cultivars increased quadratically ($P \leq 0.048$) over fall harvest dates, reaching a maximum of 3,967 kg/ha for Ogle oat. All oat cultivars exhibited stem elongation and also displayed a collective 2 to 1 yield advantage over vegetative wheat cultivars on the final (October 30) harvest date. Growing conditions were more favorable during 2007, and yields were improved for all cultivars. Yields of DM for all cultivars increased quadratically ($P \leq 0.021$) across harvest dates, and oat cultivars maintained the identical 2 to 1 yield advantage over wheat cultivars (6,275 vs. 3,203 kg/ha) that was observed for 2006. Triticale exhibited yields intermediate between oat and wheat during both years. Concentrations of NDF increased quadratically ($P \leq 0.012$) across harvest dates for all cultivars during both years of the experiment; however, these increases occurred primarily between mid September and early October with limited responses thereafter. Oat and triticale cultivars had greater ($P < 0.001$) concentrations of NDF than wheat cultivars on 5 of 6 harvest dates throughout the experiment. Estimates of TDN exhibited various polynomial responses to harvest date during 2006, but the magnitude of these changes was relatively small. During 2007, TDN declined linearly ($P \leq 0.038$) for grain-type oat, but no relationship with harvest date was observed for other cultivars ($P \geq 0.072$), including forage-type oat. Although TDN estimates generally were relatively static across harvest dates, the concentrations of truly digestible components constituting the total TDN pool were quite fluid. Generally, reductions of truly digestible CP were offset by increases in truly digestible nonfiber carbohydrate, truly digestible fiber, or both. The relatively stable energy densities for cereal-grain cultivars observed across harvest dates suggest that a broad window of opportunity exists for usage, including a single harvest as silage.

Key words: cereal grain, forage dry matter yield, forage nutritive value

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INTRODUCTION

Traditionally, grain and livestock producers throughout Oklahoma and the Southern Great Plains have used hard-red winter wheat (*Triticum aestivum* L.) to produce a grain crop for cash sale, as well as to meet the nutritional requirements of grazing stocker cattle. However, this production paradigm is not necessarily appropriate for beef and dairy producers throughout other regions of the United States. From a forage-only perspective, an important criterion for evaluating cereal-grain forages is the optimization of fall growth. For beef producers, fall forage growth from cereal grains provides a source of high-quality pasture for recently weaned spring-born calves and may limit the need for supplemental hay during winter. For a broader range of livestock producers, fall forage growth from cereal grains may serve as an additional management option for extending the grazing season or to provide emergency forage after summer drought. The potential also exists to ensile cereal-grain forages in the late-fall or early winter, either routinely, or specifically after summer drought; however, critical assessment of this management option has been limited.

[1]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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In Wisconsin, spring oat has long been used as a companion crop in association with spring establishment of alfalfa (*Medicago sativa* L.). Recently, Contreras-Govea and Albrecht (2006) reported yields of oat >6 Mg/ha when establishment was shifted to early August. This study also was intriguing because it identified additional benefits of fall growth; oat varieties contained 10 to 15% less NDF and exhibited greater in vitro true digestibility (**IVTD**) and NDF digestibility, as well as increased water-soluble carbohydrates compared with identical cultivars established the following spring. Our objectives for this study were to evaluate and then compare the fall-growth potential, fiber composition, and estimates of TDN for wheat, triticale, and oat cultivars harvested throughout the fall in central Wisconsin.

MATERIALS AND METHODS

Cannulation and care of the cows were approved by the Research Animal Resources Center of the University of Wisconsin.

Establishment of Cereal-Grain Forages

This experiment was conducted over 2 successive years (2006 and 2007) on a Richwood silt loam soil, located near Prairie du Sac, WI (43°19′ N; 89°44′ W). Soil-tests indicated that the site had 3.4% OM, 25 mg/kg of P, and 85 mg/kg of K, and that soil pH was 6.4. Before fall establishment each year, the site was planted to oat each spring and subsequently harvested as silage to prevent the shattering of potentially viable oat seed that could contaminate the plots. Several days before fall establishment, the site was sprayed with a nonselective herbicide (glyphosate) to remove any volunteer weeds or grasses that had germinated since the spring oat was harvested as silage. On August 11, 2006, and August 13, 2007, any residual plant matter was mulched with a rotary lawn mower, and cereal grains were no-till seeded into replicated 5.2 × 10.0-m plots with a 1.5-m-wide Tye Pasture Pleaser drill (model 2005, AGCO Company, Duluth, GA) configured with 18-cm row spacings. For 2006, 8 cultivars were established; these included Hopewell and Kaskaskia wheat; Ogle, Drumlin, Vista, ForagePlus, and Everleaf 126 oat; and Trical 2700 triticale. Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison). Among oat cultivars, Ogle exhibits midseason maturity, whereas Drumlin and Vista are considered mid-to-late season and ForagePlus is a late-season cultivar. In Wisconsin (forage) variety trials in which harvest dates are timed to a common late boot/early heading stage, mean harvest dates for these 4 cultivars following traditional spring establishment have been June 12, 15, 16, and 23, respectively (Mochon et al., 2008). Although Everleaf 126 is not well described, the maturity characteristics observed in this experiment suggest that it matures even more slowly than ForagePlus. Among oat cultivars, Ogle, Drumlin, and Vista often are established and harvested as grain crops (grain-type), whereas ForagePlus and Everleaf have been established primarily for forage uses (forage-type). The same cultivars were evaluated during 2007, except that Everleaf 126 was not available and was therefore dropped from the experiment. Wheat, oat, and triticale cultivars were seeded at rates of 108, 134, and 123 kg/ha, respectively. Immediately after seeding, N fertilizer was applied as ammonium nitrate (34–0-0) at a rate of 56 kg of N/ha with a calibrated applicator (model 1010, Gandy Co., Owatonna, MN).

Harvest Management

On September 15, 2006, and September 19, 2007, a single 10.0-m strip was selected at random from each plot and mowed to a 5-cm stubble height with a 0.9-m-wide, self-propelled sickle-bar mower. All clipped forage was gathered immediately via gentle hand-raking and then weighed on a platform scale in tared 114-L plastic trash cans. Grab samples (~1,000 g) were dried to constant weight at 50°C to determine the percentage of DM within each grab sample, and this value then was used to calculate the yield of DM from each plot. Two additional strips (0.9 × 10.0 m) within each plot were then selected at random and clipped at intervals of approximately 3 wk; however, specific time intervals between harvests varied slightly due to intermittent periods of wet or inclement weather that made sampling impossible on some scheduled harvest dates. Actual additional harvest dates each year occurred on October 6 and 30, 2006, as well as October 10 and November 7, 2007. In addition to DM yield, canopy height was measured in association with each harvest date by measuring height (cm) from the ground to the apex of the leaf canopy or the tip of the exposed seedhead, whichever was taller. Leaves were not extended before making height measurements. Because the growth habits of the cultivars evaluated in this experiment varied widely, field notes were recorded on each harvest date describing the stage of growth for each cultivar; assessment of growth stage was based on observations from at least 3 independent tillers per plot.

Laboratory Analysis of Forages

Dried forage samples were ground through a Wiley mill (Arthur H. Thomas, Philadelphia, PA) fitted with a 1-mm screen. Forage samples were then analyzed for NDF, ADF, hemicellulose, cellulose, ADL, N, and whole-plant ash. Analysis of NDF and other fiber components were conducted sequentially, using batch procedures outlined by Ankom Technology Corp. (Fairport, NY) for an Ankom200 Fiber Analyzer. Neither sodium sulfite nor heat-stable α-amylase was included in the NDF solution. Nitrogen within each sample was quantified by a rapid combustion procedure (AOAC, 1998, official method 990.03; Elementar Americas Inc., Mt. Laurel, NJ), and CP was then calculated by multiplying the concentration of N by a factor of 6.25. Whole-plant ash was determined on 1.0-g samples of forage from each plot and reported as the percentage of total plant DM remaining after combustion in a muffle furnace at 500°C for 6 h.

Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber. Calculations of TDN by the summative equation also required estimates of residual CP that was insoluble in neutral- and acid-detergent. These were obtained from composite samples of plots (replicates) with identical treatment structures following nonsequential extraction in neutral and acid detergent, respectively. The NDF solution contained no sodium sulfite or heat-stable α-amylase; residual CP after these extractions was determined by the identical combustion procedure and 6.25 conversion factor described previously.

Procedures and apparatus for determining IVTD on selected cultivars consisted of incubating a 0.5-g sample in a 125-mL Erlenmeyer flask containing rumen fluid, buffer media, and macro- and micro-mineral solutions for 48 h (Goering and Van Soest, 1970). Incubation flasks were maintained in a water bath at 39°C and were purged continuously with CO_2. Rumen fluid was harvested from a nonlactating dairy cow fitted with a ruminal cannula and fed a diet composed of 20.7% ryelage (*Secale cereale* L.) and 78.9% alfalfa haylage (DM basis), with the balance consisting of vitamin and mineral supplements. Rumen fluid was maintained at 39°C in insulated containers purged with CO_2, mixed in a blender also purged with CO_2, and then strained through 3 layers of cheesecloth before blending with other elements of the incubation medium. After 48 h, incubations were terminated by digestion in neutral-detergent solution (Goering and Van Soest, 1970; Mertens, 1992) that included heat-stable α-amylase and sodium sulfite.

Statistics

Initially, the effects of year were included in the statistical model for the analysis of forage yield, canopy height, and indices of forage nutritive value. However, year strongly interacted with other main effects for nearly all response variables; therefore, data were sorted and reanalyzed by year as a split-plot design using PROC GLM (SAS Inst. Inc., Cary, NC). Cereal-grain cultivars were analyzed as the whole-plot effect, and the 3 harvest dates were evaluated as subplots. Within the whole-plot treatment structure, cultivars were arranged randomly within 4 complete field blocks and tested for significance with the cultivar × block mean square as the error term. Other treatment effects or interactions were tested with the residual error mean square.

Within each year, main effects of cultivar and harvest date interacted frequently across nearly all response variables; therefore, single degree of freedom orthogonal contrasts were used to test each individual cultivar for linear and quadratic effects of harvest date. Because harvest dates were sometimes delayed slightly because of inclement weather and were therefore not equally spaced, PROC IML of SAS was used to adjust coefficients for orthogonality before evaluating trends over harvest dates. To assess the effects of cultivar, data were sorted by harvest date and then cultivars were compared within harvest date using 5 single df contrasts: i) all elongating cultivars (oat and triticale) vs. vegetative (wheat), ii) triticale vs. wheat, iii) oat vs. triticale, iv) grain vs. forage-type oat, and v) mid-maturity (Ogle) vs. mid-to-late maturity (Drumlin and Vista) within grain-type oat cultivars.

RESULTS

Precipitation

During both years, cumulative precipitation from July through November exceeded the 30-yr norm (NOAA, 2002) for Prairie du Sac (Table 1). For 2006 (NOAA, 2006), respective monthly totals for August and September were 54 and 48 mm in excess of the expected norms, whereas other months were similar to expected norms. For 2007 (NOAA, 2007), precipitation was below normal for July, September, and November, but substantially in excess during August and October. During August 2007, cumulative monthly rainfall reached 430 mm, which was nearly 4 times the 30-yr norm; similarly, rainfall during October (103 mm) was approximately twice that expected normally (56 mm).

Growth Stage and Canopy Height

During 2006, all cultivars remained vegetative (Table 2) through the initial September 15 harvest date, and the associated canopy heights ranged tightly between 17 and 31 cm (Table 3). Across the ensuing harvest dates, canopy heights increased quadratically ($P \leq 0.007$) for all cultivars except Kaskaskia wheat ($P = 0.064$). In practice, these mostly quadratic growth responses were created by relatively rapid upright growth between September 15 and October 6, but only static responses thereafter. Among cultivars, Hopewell and Kaskaskia wheat exhibited the least upright growth during the first harvest interval, increasing by 9 and 7 cm (53 and 33%), respectively; however, canopy heights approximately doubled for all oat and triticale cultivars during the same time period. These responses were associated closely with physiological development; wheat tillers did not elongate at any time during the fall, but all oat and triticale cultivars jointed by the October 6 harvest date and exhibited between 1.0 and 2.7 palpable nodes/tiller on that date (Table 2). By the final harvest date (October 30), oat and triticale cultivars

Table 1. Monthly average temperature and monthly cumulative precipitation at Prairie du Sac, WI, from July through November of 2006 (NOAA, 2006) and 2007 (NOAA, 2007)

	Monthly precipitation, mm			Temperature,[1] °C		
Month	2006	2007	30-yr norm[2]	2006	2007	30-yr norm[2]
July	90	28	97	23.2	21.8	22.2
August	163	430	109	21.1	21.4	20.8
September	129	64	81	14.3	17.3	15.9
October	57	103	56	7.3	13.4	9.4
November	53	8	52	3.8	1.6	1.3

[1]Temperature data from Prairie du Sac were incomplete. Monthly mean temperatures for 2006 and 2007 were obtained from Baraboo, WI, which is 26 km from Prairie du Sac.

[2]NOAA (2002).

had continued to mature, exhibiting between 1.2 and 3.8 nodes/tiller. Within oat cultivars, Ogle, Drumlin, and Vista (grain-type cultivars) matured most rapidly, exhibiting from 3.3 to 3.8 nodes/tiller on the final harvest date. Forage-type oat cultivars were less advanced physiologically, exhibiting only 2.1 and 1.3 nodes/tiller for ForagePlus and Everleaf 126, respectively, whereas Trical 2700 triticale (1.2 nodes/tiller) was similar to Everleaf 126 oat. The slower physiological development of forage-type oat cultivars and triticale also affected their canopy heights; these ranged from 44 to 53 cm for these cultivars, which were notably shorter than observed for grain-type oat cultivars (55 to 63 cm).

During 2007, developmental trends were similar to those observed for the previous year. Canopy heights for all cultivars increased quadratically ($P \leq 0.020$) over harvest dates, although vegetative tillers for both wheat cultivars lost their erect nature in response to freezing temperatures that occurred over the last harvest interval. In contrast to 2006, weather conditions during 2007 included above normal precipitation during August and October and warmer temperatures in October (Table 1). These climatic conditions resulted in oat and triticale plants that were physiologically more mature and also substantially taller than observed the previous year. Grain-type oat cultivars reached maximum canopy heights ranging from 88 to 104 cm, whereas ForagePlus reached a maximum of 74 cm. Ogle and Drumlin oat exhibited visible seedheads by the final harvest date, whereas ForagePlus reached a mean of 5.2 palpable nodes. In contrast, Trical 2700 triticale matured more slowly than ForagePlus, exhibiting only 1.8 nodes/tiller by the final harvest date (Table 2).

Forage Yield

During both years, yields of forage DM increased over harvest dates with significant linear ($P < 0.001$) and quadratic ($P \leq 0.048$) effects for all cereal-grain cultivars (Table 4). However, unlike responses for canopy height in which upright growth between the last 2 harvest dates of each year was generally static, all cultivars continued to accumulate DM during this final harvest interval, but at a rate slower than observed between the initial 2 harvest dates. Averaged over all cultivars, increases in DM yield between the final 2 harvest dates were only 57 and 52% of those observed during the initial harvest intervals for 2006 and 2007, respectively.

During 2006, yields of DM were less for wheat cultivars, which remained vegetative across all harvest dates, compared with oat and triticale cultivars ($P < 0.001$; Table 5). By the final harvest date, this differential was approximately 2:1 (2,975 vs. 1,589 kg/ha; $P < 0.001$), which is consistent with other reports (Maloney et al., 1999; Gunsaulis et al., 2008). Although Trical 2700 triticale generally matured more slowly than oat cultivars, it still maintained a substantial (44 to 79%) production advantage ($P \leq 0.003$) over wheat across all harvest dates. Yield of oat and triticale cultivars did not differ ($P = 0.594$) on the September 15 harvest date, but oat cultivars exhibited a production advantage ($P < 0.001$) on subsequent dates, reaching a collective differential of 826 kg/ha by October 30. Yields of DM for grain-type oat cultivars exceeded those of forage-types on October 30 (3,416 vs. 2,657 kg/ha; $P < 0.001$), but no differences were observed on previous harvest dates ($P \geq 0.093$). Within grain-type oat cultivars, the mid-maturity cultivar (Ogle) did not differ ($P = 0.142$) from mid-to-late maturity cultivars (Drumlin and Vista) on September 15. However, the more rapidly maturing Ogle exhibited yield advantages over Drumlin and Vista on both October 6 (2,419 vs. 2,035 kg/ha; $P = 0.001$) and October 30 (3,967 vs. 3,141 kg/ha; $P = 0.001$).

During 2007, fall precipitation and temperatures were more favorable for growth, resulting in a mean yield across all cultivars of 5,108 kg/ha on the final harvest date, which was 94% greater than observed the previous year (2,628 kg/ha). As observed for 2006, oat and triticale cultivars exhibited greater yields of DM ($P < 0.001$; Table 5) on all harvest dates than wheat cultivars that remained vegetative throughout the fall. This differential on the final harvest date (5,870 vs. 3,203 kg/ha; $P < 0.001$) also approached the approximate 2:1 ratio observed the previous year. Trical 2700 triticale did not differ ($P = 0.109$) from wheat cultivars on September 19, but differed by 570 ($P = 0.006$) and 1,047 kg/ha ($P = 0.007$) on October 10 and November 7, respectively. Yields of DM from oat cultivars exceeded those of triticale across all harvest dates ($P < 0.001$), reaching a maximum differential on November 7 (6,275 vs. 4,250 kg/ha). Similarly, grain-type oat cultivars yielded more forage DM on the final harvest date than ForagePlus (6,478 vs. 5,664 kg/ha; $P = 0.021$), which also was consistent with results from the previous year. Within grain-type oat cultivars, yields of DM from Ogle did not differ from mid-to-late maturing cultivars on the initial ($P = 0.875$) or final ($P = 0.458$) harvest dates but did exhibit a relatively small production advantage (4,986 vs. 4,594 kg/ha; $P = 0.046$) on October 10.

Nutritive Value

Effects of Harvest Date 2006. Concentrations of NDF increased with linear ($P \leq 0.028$) and quadratic ($P < 0.001$) effects of time for all cereal-grain cultivars (Table 6), but did not exceed 49.8% for any cultivar on any harvest date. Generally, the quadratic responses were created by increased NDF between September 15 and October 6, followed by static or declining concentrations thereafter. The increased concentrations of NDF during the first harvest interval tended to be greater for oat and triticale cultivars, ranging from 7.0 to a maximum of 10.8 percentage units for Ogle oat, and coincided with active stem elongation during this time period (Table 2). In contrast, wheat cultivars exhibited more limited responses (4.3 to 5.3 percentage units) during this initial harvest interval, mostly likely because they remained strictly vegetative. The static responses or reduced concentrations of NDF observed after October 6 are particularly interesting because they occurred during a time period in which all cultivars exhibited concomitant increases in DM yield and oat tillers continued to elongate.

Generally, concentrations of ADF, hemicellulose, and cellulose exhibited similar response patterns throughout the fall for all cultivars. For ADF and cellulose, a quadratic effect ($P < 0.001$) of harvest date was observed for all cultivars, which included increased concentrations of both fiber components over the first harvest interval but reduced concentrations for all cultivars thereafter. Concentrations of hemicellulose increased linearly ($P < 0.001$) for all cultivars, but these responses also were coupled with quadratic effects for Kaskaskia wheat ($P = 0.029$) and Ogle, Drumlin, Vista, and ForagePlus oat ($P \leq 0.011$). For hemicellulose, concentrations continued to increase between the second and third harvest dates for all cultivars except Vista oat; however, averaged over all cultivars, the magnitude of these increases was only about 33% of those observed during the first harvest interval. During 2006, concentrations of ADL were small, ranging from 0.28 to 0.85% across all cultivars and harvest dates. Generally, concentrations of ADL were affected only minimally by harvest date during 2006; a quadratic effect was observed for Vista (P

Table 2. Growth stage for cereal-grain forages on each harvest date over 2 yr at Prairie du Sac, WI[1]

	Winter wheat		Spring oats					Triticale
Harvest date	Hopewell	Kaskaskia	Ogle	Drumlin	Vista	ForagePlus	Everleaf 126	Trical 2700
2006								
September 15	Vegetative	Vegetative	Vegetative	Vegetative	Vegetative	Vegetative	Vegetative	Vegetative
October 6	Vegetative	Vegetative	Elongated (2.6)[2]	Elongated (2.7)	Elongated (2.7)	Elongated (1.8)	Elongated (1.0)	Elongated (1.3)
October 30	Vegetative	Vegetative	Elongated (3.8)	Elongated (3.3)	Elongated (3.3)	Elongated (2.1)	Elongated (1.3)	Elongated (1.2)
2007								
September 19	Vegetative	Vegetative	Elongated (1.3)	Elongated (0.9)	Elongated (0.8)	Vegetative	. . .	Vegetative
October 10	Vegetative	Vegetative	Early boot	Early boot	Elongated (4.9)	Elongated (3.5)	. . .	Elongated (1.0)
November 7	Vegetative	Vegetative	Heading	Early heading	Late boot	Elongated (5.2)	. . .	Elongated (1.8)

[1]Everleaf 126 oat was not available in 2007. Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison).

[2]Plants were post-jointing with actively elongating stems. The number shown in parentheses represents the mean number of palpable nodes on each tiller.

Table 3. Canopy height (cm) on 3 harvest dates during 2006 and 2007 for cereal-grain forages planted in early August near Prairie du Sac, WI[1]

	Winter wheat		Spring oats					Triticale
Harvest date	Hopewell	Kaskaskia	Ogle	Drumlin	Vista	ForagePlus	Everleaf 126	Trical 2700
2006								
September 15	17	21	29	23	31	30	25	24
October 6	26	28	62	57	59	53	51	40
October 30	25	29	63	55	58	53	47	44
SEM					1.5			
Contrast,[2] $P > F$								
Linear	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.007	0.064	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
2007								
September 19	20	23	39	37	45	41	. . .	25
October 10	40	38	88	94	88	74	. . .	47
November 7	23	25	104	99	86	70	. . .	53
SEM					2.5			
Contrast,[2] $P > F$								
Linear	0.709	0.598	<0.001	<0.001	0.001	<0.001	. . .	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	0.006	0.001	. . .	0.020

[1]Everleaf 126 oat was not available in 2007. Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison).

[2]Linear and quadratic effects of harvest date.

= 0.044) and ForagePlus oat (P = 0.004), but other cultivars were not affected ($P \geq 0.064$).

Concentrations of CP decreased over time with linear ($P < 0.001$) and quadratic ($P < 0.001$) effects for all cereal-grain cultivars. Initially, concentrations of CP for all cultivars were high (≥31.2%), but declined thereafter, ranging between 13.3 and 18.8% on the final harvest date. Whole-plant ash declined linearly ($P \leq 0.003$) across harvest dates for all cultivars, but quadratic effects were not significant ($P \geq 0.168$). When averaged over all cultivars, concentrations of ash declined by 4.0 percentage units between the first and last harvest dates. This observation has specific relevance with respect to calculation of TDN because ash contains no energy and is therefore subtracted from total plant DM during estimation of nonfiber carbohydrate and subsequent calculation of TDN by the summative model (Weiss et al., 1992; NRC, 2001). Concentrations of TDN for the 8 cultivars exhibited varying polynomial effects over harvest dates; these included linear responses for Kaskaskia wheat ($P < 0.001$) and Everleaf 126 oat (P = 0.009), quadratic effects for Ogle (P = 0.028), Vista (P = 0.018), and ForagePlus oat (P = 0.001), but no response for other cultivars ($P \geq 0.077$).

Table 4. Yields of DM (kg/ha) for cereal-grain forages planted in early August 2006 and 2007 near Prairie du Sac, WI[1]

	Winter wheat		Spring oats					Triticale
Harvest date	Hopewell	Kaskaskia	Ogle	Drumlin	Vista	ForagePlus	Everleaf 126	Trical 2700
2006								
September 15	237	286	515	425	483	493	518	468
October 6	1,070	1,298	2,419	2,056	2,014	1,927	2,147	1,730
October 30	1,470	1,708	3,967	3,086	3,195	2,734	2,580	2,286
SEM				103.4				
Contrast,[2] $P > F$								
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.048	0.009	0.025	0.004	0.042	0.004	<0.001	0.002
2007								
September 19	461	683	1,415	1,323	1,481	1,246	. . .	711
October 10	2,400	2,388	4,986	4,561	4,626	4,070	. . .	2,964
November 7	3,137	3,269	6,650	6,527	6,257	5,664	. . .	4,250
SEM				203.0				
Contrast,[2] $P > F$								
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	. . .	<0.001
Quadratic	0.003	0.021	<0.001	<0.001	<0.001	0.001	. . .	0.005

[1]Everleaf 126 oat was not available in 2007. Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison).

[2]Linear and quadratic effects of harvest date.

From a practical standpoint, concentrations of TDN varied only minimally throughout the fall, regardless of cultivar, with a slight numerical increase observed on the final harvest date for all cultivars except Trical 2700 triticale.

Cultivar Effects 2006. A complete summary of contrasts comparing forage nutritive value among cultivar types for each harvest date is found in Table 7, but only those most important to interpretation of results are described and discussed. Generally, contrast analysis suggested that cultivar groups exhibited increasingly diverse characteristics over time. On September 15, all cultivars remained vegetative and concentrations of NDF varied only between forage and grain-type oat (37.3 vs. 38.8%; $P = 0.008$); although the magnitude of this difference was relatively small, it was accompanied by similar differences for concentrations of ADF (20.8 vs. 21.8%; $P = 0.026$), cellulose (17.8 vs. 18.7%; $P = 0.007$), and ADL (0.36 vs. 0.60%; $P = 0.006$). No contrast differed for CP ($P \geq 0.122$) or TDN ($P = 0.211$) on the initial harvest date.

By October 6, jointing had occurred for all oat and triticale cultivars, resulting in greater concentrations of NDF compared with wheat cultivars that remained vegetative (47.2 vs. 42.7%; $P < 0.001$). Mostly, this difference can be attributed to concomitant increases in concentrations of cellulose (25.3 vs. 20.6%; $P < 0.001$), but not hemicellulose ($P = 0.692$). Vegetative wheat cultivars maintained greater concentrations of CP than oat and triticale cultivars (22.5 vs. 18.5%; $P < 0.001$), as well as slightly greater estimates of TDN (69.3 vs. 67.8%; $P = 0.001$). When triticale alone was compared with wheat cultivars, similar differences again were observed for NDF (47.3 vs. 42.7%; $P < 0.001$), cellulose (25.3 vs. 20.6%; $P < 0.001$), CP (20.5 vs. 22.5%; $P = 0.003$), and TDN (67.6 vs. 69.3%; $P = 0.010$). Oat cultivars differed from triticale for CP (18.1 vs. 20.5%; $P < 0.001$) and whole-plant ash (11.7 vs. 12.5%; $P = 0.014$), but not for other indices of nutritive value ($P \geq 0.347$). Within oat cultivars, grain types exhibited greater concentrations of NDF, ADF, hemicellulose, and cellulose ($P \leq 0.005$) than forage types, but TDN did not differ ($P = 0.091$). Similarly, the mid-maturity grain-type oat cultivar (Ogle) had greater ($P \leq 0.016$) concentrations of NDF, ADF, and cellulose than mid-to-late maturity cultivars (Drumlin and Vista), but there was no difference for hemicellulose ($P = 0.488$) and only a tendency for TDN to differ ($P = 0.056$).

Generally, most trends comparing cultivars that were observed on the October 6 harvest date also were detected on the final harvest date. One notable exception occurred in contrasts of triticale with all oat cultivars, which differed ($P \leq 0.014$) only for CP and whole-plant ash on 6 October. By the final harvest date, triticale had greater concentrations of NDF (48.2 vs. 44.4%; $P < 0.001$), ADF (26.3 vs. 23.7%; $P < 0.001$), hemicellulose (21.9 vs. 20.7%; $P = 0.014$), and cellulose (24.3 vs. 22.1%; $P \leq 0.001$) than all oat cultivars, as well as reduced estimates of TDN (68.2 vs. 71.1%; $P < 0.001$).

Table 5. Contrast analysis comparing yields of DM for cereal-grain cultivars harvested on 3 dates during 2006 and 2007 at Prairie du Sac, WI

Contrast	2006	2007
	$P > F$	
September 15		
All elongated vs. vegetative[1]	<0.001	<0.001
Wheat vs. triticale	<0.001	0.109
Triticale vs. all oat	0.594	<0.001
Forage vs. grain oat[2]	0.305	0.053
Grain oat: mid vs. mid-to-late[3]	0.142	0.875
October 6		
All elongated vs. vegetative	<0.001	<0.001
Wheat vs. triticale	<0.001	0.006
Triticale vs. all oat	<0.001	<0.001
Forage vs. grain oat	0.093	0.001
Grain oat: mid vs. mid-to-late	0.001	0.046
October 30		
All elongated vs. vegetative	<0.001	<0.001
Wheat vs. triticale	0.003	0.007
Triticale vs. all oat	<0.001	<0.001
Forage vs. grain oat	<0.001	0.021
Grain oat: mid vs. mid-to-late	0.001	0.458

[1]Comparison of all cultivars (oat and triticale) expected to elongate after establishment in early August vs. wheat.

[2]Forage cultivars: ForagePlus (Wisconsin Foundation Seeds, Madison) and Everleaf 126 (2006 only; Wolf River Valley Seeds, White Lake, WI); grain cultivars: Ogle, Drumlin, and Vista (Wisconsin Foundation Seeds).

[3]Mid-maturity grain cultivar: Ogle; mid-to-late grain cultivars: Drumlin and Vista.

Effects of Harvest Date 2007. Growing conditions during 2007 permitted more advanced tiller development, particularly within oat cultivars, compared with observations made during 2006 (Table 2). As a result, concentrations of NDF generally were greater for all cultivars in 2007 (Table 8), reaching a maximum of 62.7% for Ogle oat on the final harvest date. On this date, Ogle oat was fully headed, which was the most advanced growth stage exhibited by any cultivar during either year of the experiment. For all cultivars, concentrations of NDF, ADF, and cellulose increased with both linear ($P \leq 0.002$) and quadratic ($P \leq 0.012$) effects over time. For all 3 fiber components, the quadratic character of these responses was derived from the sharp increases between the first and second harvest dates followed by static responses for all cultivars thereafter. For example, the mean concentration of NDF averaged across all cultivars was 43.1% on September 19, and then increased sharply to 54.4% by October 10; however, the concentration of NDF on the final harvest date (55.6%) represented little additional change. The static responses for these fiber components over the final harvest interval is unique because all oat and triticale cultivars continued their physiological development during this time period (Table 2), and the mean yield of DM across these same cultivars increased by 38% over this same time interval (Table 4).

Concentrations of hemicellulose increased over harvest dates for all cultivars, exhibiting linear ($P < 0.001$)

Table 6. Concentrations of fiber components, CP, whole-plant ash, and TDN (% of DM) for cereal-grain forages established on August 11, 2006, near Prairie du Sac, WI[1]

	Winter wheat		Spring oats					Triticale
Harvest date	Hopewell	Kaskaskia	Ogle	Drumlin	Vista	ForagePlus	Everleaf 126	Trical 2700
NDF								
September15	37.3	38.5	39.0	38.9	38.5	36.6	37.9	39.0
October 6	42.6	42.8	49.8	47.8	47.5	46.1	44.9	47.3
October 30	42.4	40.5	47.4	46.2	42.3	43.3	42.8	48.2
Contrast,[2,3] $P > F$								
Linear	<0.001	0.028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ADF								
September 15	20.1	21.7	22.6	21.5	21.3	20.5	21.0	22.1
October 6	22.5	23.1	29.1	26.9	27.3	26.7	25.9	27.3
October 30	20.2	19.8	25.7	24.1	22.3	23.2	23.2	26.3
Contrast,[2,3] $P > F$								
Linear	0.946	0.001	<0.001	<0.001	0.235	<0.001	0.001	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hemicellulose								
September 15	17.2	16.8	16.4	17.4	17.2	16.0	16.9	16.9
October 6	20.2	19.7	20.8	20.8	20.2	19.4	19.0	20.0
October 30	22.2	20.7	21.7	22.1	20.1	20.1	19.6	21.9
Contrast,[2,3] $P > F$								
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.182	0.029	<0.001	0.011	0.001	0.003	0.088	0.115
Cellulose								
September 15	17.2	17.8	19.0	18.8	18.3	18.1	17.4	19.0
October 6	20.3	20.8	27.0	25.0	25.3	25.0	24.1	25.3
October 30	18.4	18.1	24.0	22.5	20.9	21.6	21.5	24.3
Contrast,[2,3] $P > F$								
Linear	0.027	0.772	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ADL								
September 15	0.52	0.72	0.59	0.58	0.64	0.28	0.44	0.66
October 6	0.69	0.82	0.85	0.62	0.80	0.66	0.51	0.59
October 30	0.70	0.51	0.79	0.63	0.44	0.29	0.70	0.69
Contrast,[2,3] $P > F$								
Linear	0.219	0.132	0.173	0.753	0.141	0.921	0.064	0.768
Quadratic	0.475	0.112	0.188	0.876	0.044	0.004	0.681	0.473
CP								
September 15	31.7	31.2	31.5	32.1	31.4	32.8	32.0	31.2
October 6	23.4	21.5	17.8	19.0	18.1	18.1	17.6	20.5
October 30	18.8	18.2	13.3	15.5	15.3	15.4	15.3	17.5
Contrast,[2,3] $P > F$								
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Whole-plant ash								
September 15	12.6	14.9	14.9	13.4	13.3	13.8	14.5	14.3
October 6	11.4	11.2	11.5	11.9	10.9	12.4	11.7	12.5
October 30	9.5	9.1	9.3	10.0	9.4	10.9	9.8	11.8
Contrast,[2,3] $P > F$								
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.003
Quadratic	0.758	0.168	0.285	0.932	0.390	0.930	0.369	0.372
TDN[4]								
September 15	69.8	66.6	67.2	68.6	68.1	70.0	68.0	68.2
October 6	69.2	69.4	66.7	67.9	68.0	67.7	69.0	67.6
October 30	71.5	73.0	70.4	70.4	72.5	71.6	70.8	68.2
Contrast,[2,3] $P > F$								
Linear	0.093	<0.001	0.002	0.077	<0.001	0.086	0.009	0.992
Quadratic	0.131	0.839	0.028	0.094	0.018	0.001	0.681	0.482

[1]Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison).

[2]Linear and quadratic effects of harvest date.

[3]The pooled SEM across all cereal-grain forages was NDF = 0.60%, ADF = 0.40%, hemicellulose = 0.39%, cellulose = 0.32%, ADL = 0.099%, CP = 0.45%, whole-plant ash = 0.56%, and TDN = 0.72%.

[4]Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

Table 7. Contrast analysis comparing indices of nutritive value for cereal-grain cultivars harvested on 3 dates during 2006 in Prairie du Sac, WI

Contrast	NDF	ADF	Hemicellulose	Cellulose	ADL	CP	Ash	TDN[1]
	$P > F$							
September 15								
All elongated vs. vegetative[2]	0.366	0.126	0.558	0.005	0.252	0.366	0.661	0.844
Wheat vs. triticale	0.126	0.055	0.899	0.003	0.721	0.642	0.586	0.984
Triticale vs. all oat	0.204	0.209	0.722	0.091	0.139	0.159	0.734	0.882
Forage vs. grain oat[3]	0.008	0.026	0.174	0.007	0.006	0.122	0.735	0.211
Grain oat: mid vs. mid-to-late[4]	0.691	0.062	0.078	0.272	0.863	0.725	0.145	0.319
October 6								
All elongated vs. vegetative	<0.001	<0.001	0.692	<0.001	0.315	<0.001	0.043	0.001
Wheat vs. triticale	<0.001	<0.001	0.855	<0.001	0.175	0.003	0.003	0.010
Triticale vs. all oat	0.866	0.735	0.913	0.886	0.347	<0.001	0.014	0.646
Forage vs. grain oat	<0.001	0.002	<0.001	0.005	0.065	0.300	0.035	0.091
Grain oat: mid vs. mid-to-late	0.016	0.002	0.488	0.003	0.259	0.214	0.683	0.056
October 30								
All elongated vs. vegetative	<0.001	<0.001	0.109	<0.001	0.870	<0.001	0.002	0.001
Wheat vs. triticale	<0.001	<0.001	0.389	<0.001	0.422	0.134	<0.001	<0.001
Triticale vs. all oat	<0.001	<0.001	0.014	<0.001	0.226	<0.001	<0.001	<0.001
Forage vs. grain oat	0.002	0.021	0.001	0.013	0.135	0.178	0.008	0.796
Grain oat: mid vs. mid-to-late	0.002	<0.001	0.257	<0.001	0.029	0.004	0.289	0.110

[1]Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

[2]Comparison of all cultivars (oat and triticale) expected to elongate after establishment in early August vs. wheat.

[3]Forage cultivars: ForagePlus (Wisconsin Foundation Seeds, Madison) and Everleaf 126 (Wolf River Valley Seeds, White Lake, WI); grain cultivars: Ogle, Drumlin, and Vista (Wisconsin Foundation Seeds).

[4]Mid-maturity grain cultivar: Ogle; mid-to-late grain cultivars: Drumlin and Vista.

effects in each case. For oat cultivars, quadratic ($P \leq 0.001$) effects also were observed, which were likely related to static responses over the final harvest interval. Unlike 2006, ADL increased with significant polynomial effects across harvest dates for all cultivars except Trical 2700 triticale ($P \geq 0.194$). For other cultivars, these responses included linear ($P \leq 0.017$) effects for wheat cultivars and ForagePlus oat, but also quadratic ($P \leq 0.036$) effects for Ogle, Drumlin, and Vista oat. Generally, concentrations of ADL were greater for all cultivars in 2007 compared with the previous year. During 2006, the maximum concentration of ADL observed for any cultivar on any harvest date was 0.85%. In contrast, this threshold was exceeded by all cultivars, regardless of growth stage, on the final 2 harvest dates of 2007, and reached a maximum concentration of 3.71% for fully headed Ogle oat. Unlike 2006, concentrations of ADL within oat cultivars also were correlated closely with growth stage; on the final harvest date, concentrations of ADL ranged from 3.71% for fully headed Ogle down to 1.42% for ForagePlus, which had not yet reached boot stage.

Concentrations of CP declined ($P \leq 0.031$) throughout the fall for all cultivars during 2007; these effects were linear ($P < 0.001$) across all cultivars and were coupled with quadratic ($P \leq 0.031$) effects for oat cultivars. Concentrations of whole-plant ash declined numerically over harvest dates for all cultivars, largely through dilution, but responses were linear only for Hopewell wheat ($P = 0.018$) and Drumlin oat ($P = 0.041$), and no quadratic effects were observed for any cultivar ($P \geq 0.394$). Total digestible nutrients did not change ($P \geq 0.072$) across harvest dates for wheat and triticale cultivars, as well as ForagePlus oat. Grain-type oat cultivars, which exhibited the most advanced growth stages on all harvest dates, exhibited linear ($P \leq 0.038$) declines for TDN; however, these changes tended to be disproportionately weighted between the first and second harvest dates, thereby resulting in additional quadratic ($P \leq 0.073$) tendencies for Ogle and Drumlin oat. Overall estimates of TDN generally were greater for cultivars during 2006 compared with 2007.

Cultivar Effects 2007. A summary of comparisons of cultivar groups within each harvest date during 2007 is found in Table 9; however, only those contrasts most important to interpretation of results are described and discussed. Unlike 2006, grain-type oat cultivars had jointed by the first (September 19) harvest date; as a result, elongating cultivars (oat and triticale) exhibited greater concentrations of NDF than wheat cultivars that remained vegetative throughout the fall (43.6 vs. 41.8%; $P < 0.001$). Similarly, concentrations of NDF were greater for oat cultivars than triticale (44.0 vs. 41.9%; $P < 0.001$) and greater for grain- compared with forage-type oat (44.6 vs. 42.2%; $P < 0.001$). Although these differences among cultivar groups were statistically significant, their magnitude was generally small ($\leq$2.4 percentage units), and concentrations of ADL ($P \geq 0.083$), CP ($P \geq 0.172$), and TDN ($P \geq 0.171$) were not affected.

By the October 10 harvest date, all oat and triticale cultivars had jointed, and this resulted in sharply

Table 8. Concentrations of fiber components, CP, whole-plant ash, and TDN (% of DM) for cereal-grain forages established on August 13, 2007, near Prairie du Sac, WI[1]

	Winter wheat		Spring oats				Triticale
Harvest date	Hopewell	Kaskaskia	Ogle	Drumlin	Vista	ForagePlus	Trical 2700
NDF							
September 19	40.9	42.7	45.0	44.1	44.6	42.2	41.9
October 10	47.6	50.0	60.5	59.9	57.6	54.0	51.3
November 7	49.6	51.0	62.7	61.6	57.8	55.6	51.2
Contrast,[2,3] $P > F$							
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.012	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
ADF							
September 19	20.6	23.3	26.0	25.1	25.2	24.4	22.8
October 10	25.3	27.7	36.9	35.7	33.9	31.6	29.8
November 7	25.0	27.3	37.7	36.5	33.4	32.1	28.5
Contrast,[2,3] $P > F$							
Linear	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.007	0.008	<0.001	<0.001	<0.001	<0.001	<0.001
Hemicellulose							
September 19	20.3	19.4	19.0	18.9	19.4	17.8	19.1
October 10	22.4	22.3	23.6	24.3	23.7	22.5	21.5
November 7	24.6	23.7	25.0	25.1	24.4	23.5	22.6
Contrast,[2,3] $P > F$							
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.687	0.067	0.001	<0.001	<0.001	<0.001	0.102
Cellulose							
September 19	17.6	19.7	23.3	22.5	23.0	21.7	20.9
October 10	22.1	24.1	33.2	32.1	30.8	29.0	27.2
November 7	22.2	24.4	33.1	32.0	29.6	29.7	26.0
Contrast,[2,3] $P > F$							
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ADL							
September 19	0.64	0.73	0.76	0.50	0.58	0.55	0.56
October 10	0.93	1.36	2.58	2.47	1.94	1.13	0.98
November 7	1.43	1.36	3.71	3.26	2.68	1.42	0.90
Contrast,[2,3] $P > F$							
Linear	0.002	0.017	<0.001	<0.001	<0.001	0.001	0.198
Quadratic	0.823	0.093	0.011	0.001	0.036	0.320	0.194
CP							
September 19	34.9	33.6	33.3	32.7	31.8	33.5	30.3
October 10	30.5	27.9	19.5	20.2	20.3	22.1	27.2
November 7	23.9	22.0	13.7	13.9	17.0	16.6	20.7
Contrast,[2,3] $P > F$							
Linear	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Quadratic	0.859	0.708	0.006	0.023	0.008	0.031	0.568
Whole-plant ash							
September 19	15.8	14.2	13.0	14.0	12.7	15.4	12.3
October 10	14.6	14.0	11.8	12.1	10.8	13.3	13.6
November 7	11.2	11.3	9.8	10.0	9.7	11.6	12.0
Contrast,[2,3] $P > F$							
Linear	0.018	0.123	0.099	0.041	0.133	0.058	0.812
Quadratic	0.638	0.511	0.916	0.899	0.711	0.808	0.394
TDN[4]							
September 19	66.5	67.3	67.2	66.9	67.7	65.6	69.6
October 10	64.7	63.5	59.8	60.0	63.0	63.1	64.5
November 7	66.1	65.5	59.2	60.3	62.3	64.3	66.8
Contrast,[2,3] $P > F$							
Linear	0.918	0.533	0.003	0.014	0.038	0.634	0.326
Quadratic	0.444	0.153	0.073	0.062	0.276	0.370	0.072

[1]Everleaf 126 oat was not available in 2007. Trical 2700 triticale and Everleaf 126 oat were obtained through Wolf River Valley Seeds (White Lake, WI); all other cultivars were obtained through Wisconsin Foundation Seeds (Madison).

[2]Linear and quadratic effects of harvest date.

[3]The pooled SEM across all cereal-grain forages was NDF = 0.60%, ADF = 0.40%, hemicellulose = 0.39%, cellulose = 0.32%, ADL = 0.099%, CP = 1.52%, whole-plant ash = 1.35%, and TDN = 1.72%.

[4]Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

Table 9. Contrast analysis comparing indices of nutritive value for cereal-grain cultivars harvested on 3 dates during 2007 near Prairie du Sac, WI

Contrast	NDF	ADF	Hemicellulose	Cellulose	ADL	CP	Ash	TDN[1]
	P > F							
September 19								
All elongated vs. vegetative[2]	<0.001	<0.001	0.011	<0.001	0.259	0.326	0.271	0.748
Wheat vs. triticale	0.951	0.171	0.144	<0.001	0.300	0.172	0.184	0.222
Triticale vs. all oat	<0.001	<0.001	0.590	<0.001	0.716	0.330	0.418	0.171
Forage vs. grain oat[3]	<0.001	0.076	0.015	<0.001	0.539	0.754	0.260	0.418
Grain oat: mid vs. mid-to-late[4]	0.139	0.173	0.718	0.038	0.083	0.715	0.851	0.954
October 10								
All elongated vs. vegetative	<0.001	<0.001	0.055	<0.001	<0.001	<0.001	<0.001	0.002
Wheat vs. triticale	0.013	<0.001	0.167	<0.001	0.307	0.041	0.288	0.625
Triticale vs. all oat	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.013	0.001
Forage vs. grain oat	<0.001	<0.001	0.017	<0.001	<0.001	0.026	0.008	0.012
Grain oat: mid vs. mid-to-late	0.084	0.001	0.526	0.001	0.027	0.425	0.580	0.055
November 7								
All elongated vs. vegetative	<0.001	<0.001	0.997	<0.001	<0.001	<0.001	0.146	<0.001
Wheat vs. triticale	0.456	0.008	0.003	0.001	0.063	0.006	0.185	0.292
Triticale vs. all oat	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001
Forage vs. grain oat	<0.001	<0.001	0.004	0.010	<0.001	0.019	0.004	0.001
Grain oat: mid vs. mid-to-late	0.015	0.003	0.560	0.005	0.009	0.029	0.922	0.035

[1]Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

[2]Comparison of all cultivars (oat and triticale) expected to elongate after establishment in early August vs. wheat.

[3]Forage cultivar: ForagePlus; grain cultivars: Ogle, Drumlin, and Vista (seeds from Wisconsin Foundation Seeds, Madison).

[4]Mid-maturity grain cultivar: Ogle; mid-to-late grain cultivars: Drumlin and Vista.

greater concentrations of NDF for all elongating cultivars compared with wheat (56.7 vs. 48.8%; $P < 0.001$). A similar relationship was found for triticale alone compared with wheat (51.3 vs. 48.8%; $P = 0.013$). Stem elongation was more advanced for all oat cultivars (Table 2) than for triticale, and this affected their respective concentrations of NDF (58.0 vs. 51.3%; $P < 0.001$); similar relationships also were observed between grain- and forage-type oat cultivars (59.3 vs. 54.0%; $P < 0.001$). Within each of these group comparisons, greater NDF was accompanied by less CP ($P \leq 0.041$) and reduced TDN ($P \leq 0.012$), except when wheat and triticale cultivars were compared for concentrations of TDN ($P = 0.625$).

Most of the relationships between cultivar groups identified for October 10 also were observed on November 7. One notable exception occurred within grain-type oat cultivars; the mid-season maturity cultivar (Ogle) exhibited greater concentrations of NDF (62.7 vs. 59.7%; $P = 0.015$), as well as decreased concentrations of CP (13.7 vs. 15.5%; $P = 0.029$) and TDN (59.2 vs. 61.3%; $P = 0.035$) than mid-to-late season cultivars (Drumlin and Vista). These differences were not observed on October 10 harvest date ($P \geq 0.055$).

Truly Digestible Components Constituting TDN

From a practical standpoint, concentrations of TDN for each cultivar remained relatively stable across harvest dates; this generalization appeared to break down only when tiller development advanced beyond stem elongation, which occurred only for grain-type oat cultivars during 2007. Illustrations of this concept for Kaskaskia wheat, Ogle oat, ForagePlus oat, and Trical 2700 triticale are shown in Figures 1, 2, 3, and 4, respectively. Despite the overall stability of TDN estimates throughout the fall, individual pools of truly digestible components that comprised each total energy estimate were quite fluid during this same time period. Truly digestible nonfiber carbohydrate (**TD-NFC**) increased across harvest dates for all cultivars during both years, except for triticale during 2007. Furthermore, contributions of TD-NFC to the total TDN pool were large, reaching 33 percentage units of TDN for wheat and 30 percentage units for both oat cultivars on the final harvest date of 2006. Concentrations of TDN-NFC for triticale during 2006 were somewhat less than other cultivars, reaching about 21 percentage units of TDN. It is not immediately clear why contributions from TDN-NFC generally were less for all cultivars in 2007, but this TDN component may have been depressed by the energy requirements for substantially greater DM yields observed during 2007 compared with the previous year (Table 4). Alternatively, the above normal temperatures observed during October 2007 (Table 1) potentially could have limited the accumulation of sugars that occurs typically in response to cold temperatures (Eastin and Sullivan, 1984).

Concentrations of truly digestible CP declined across harvest dates for all cultivars during both years of the experiment. Kaskaskia wheat tended to be less affected than oat or triticale cultivars, largely because it remained vegetative and maintained greater concentra-

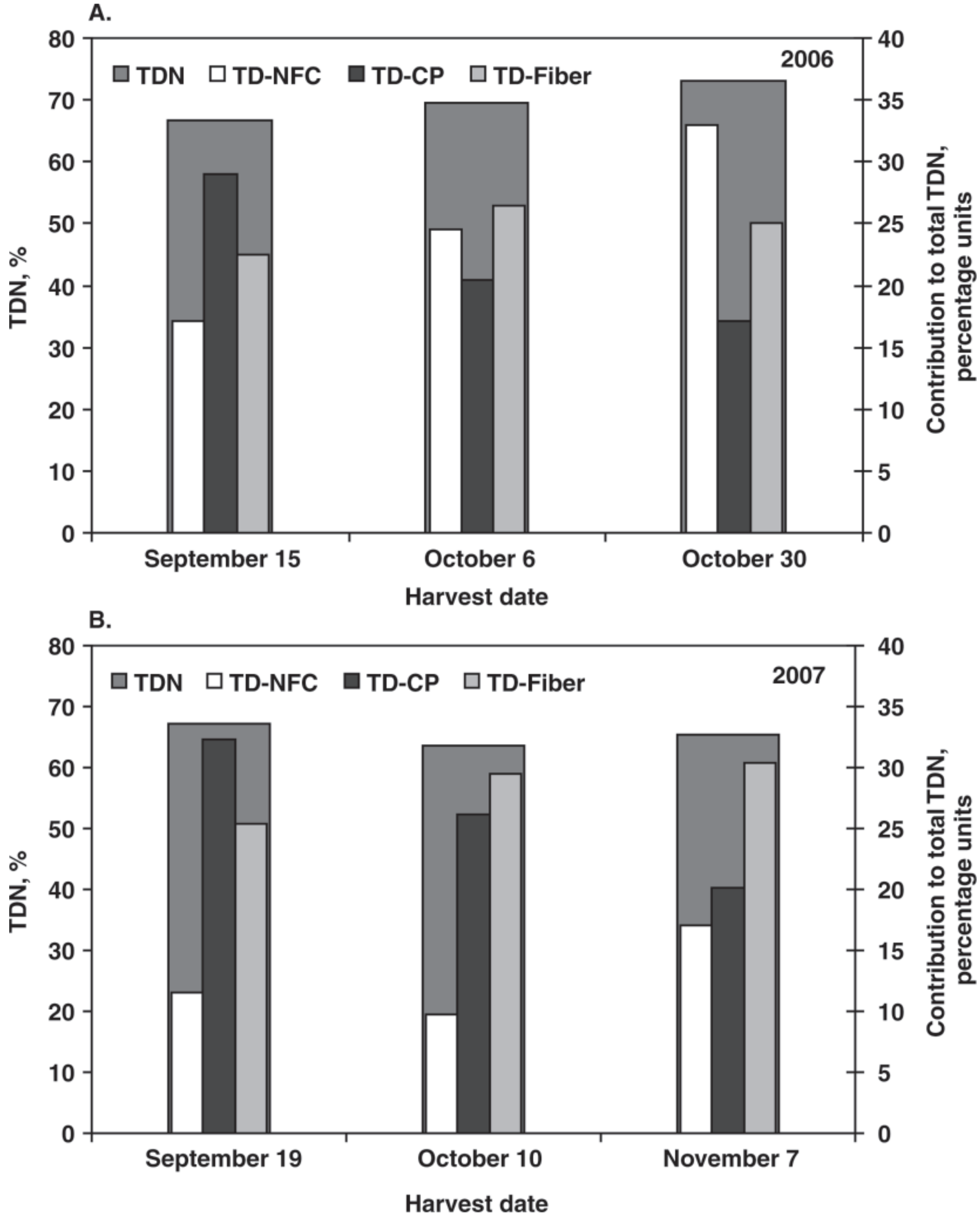

Figure 1. Concentrations of TDN for Kaskaskia wheat (Wisconsin Foundation Seeds, Madison) established in early August and harvested at approximately 3-wk intervals during 2006 (panel A) and 2007 (panel B). For 2006, a linear ($P < 0.001$) effect of harvest date was observed for concentrations of TDN, but no effects were observed for 2007 ($P \geq 0.153$). The main calculated components of total TDN, including truly digestible nonfiber carbohydrate (TD-NFC), truly digestible CP (TD-CP), and truly digestible fiber (TD-Fiber), are shown within each estimate of TDN; these components are scaled to the secondary y-axis for visual clarity. The SEM associated with each estimate of TDN was 0.72 and 1.72% for 2006 and 2007, respectively. Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

tions of CP after the initial harvest date. For all cultivars, truly digestible fiber increased sharply between the first and second harvest dates each year, largely in response to concurrent increases in NDF during this time interval, but then remained relatively stable thereafter. In addition, contributions of truly digestible fiber to the total TDN pool tended to be greater for elongating cultivars that also exhibited greater concentrations of NDF.

IVTD

The relatively stable estimates of TDN that were observed across harvest dates were corroborated by independent determinations of IVTD for Kaskaskia wheat, Ogle and ForagePlus oat, and Trical 2700 triticale (data not shown). During 2006, IVTD was not affected quadratically ($P \geq 0.410$) or linearly ($P \geq 0.059$) by harvest date for any of these cultivars. Averaged over all

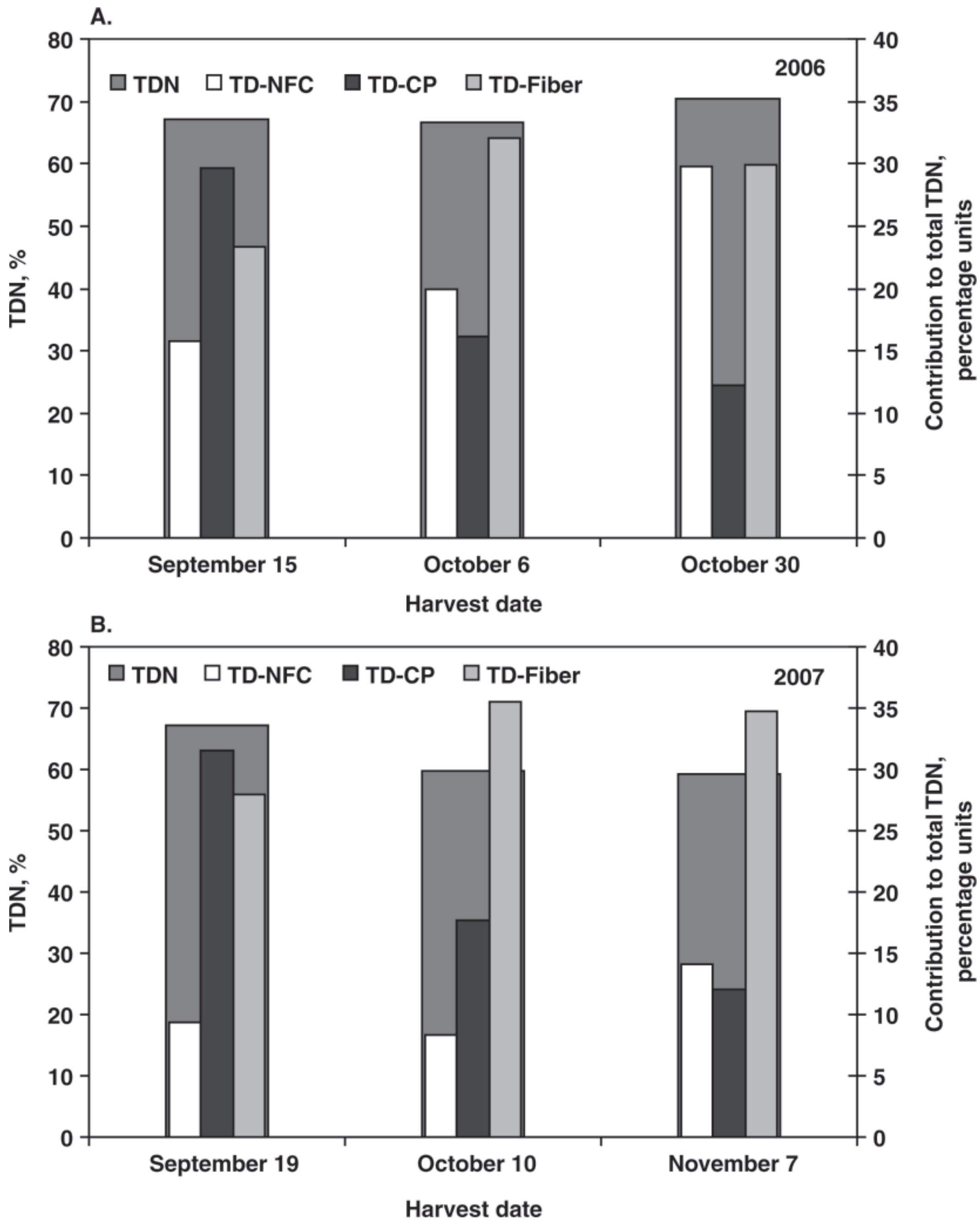

Figure 2. Concentrations of TDN for Ogle oat (Wisconsin Foundation Seeds, Madison) established in early August and harvested at approximately 3-wk intervals during 2006 (panel A) and 2007 (panel B). For 2006, harvest date exhibited linear ($P = 0.002$) and quadratic ($P = 0.028$) effects on concentrations of TDN. For 2007, only a linear ($P = 0.003$) effect was observed. The main components of total TDN, including truly digestible nonfiber carbohydrate (TD-NFC), truly digestible CP (TD-CP), and truly digestible fiber (TD-Fiber), are shown within each estimate of TDN; these components are scaled to the secondary y-axis for visual clarity. The SEM associated with each estimate of TDN was 0.72 and 1.72% for 2006 and 2007, respectively. Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

harvest dates, concentrations of IVTD were extremely large, ranging narrowly from 89.1% for Ogle oat to a numerical maximum of 91.2% for ForagePlus oat. For 2007, IVTD did not change in linear ($P \geq 0.095$) or quadratic ($P \geq 0.267$) patterns across harvest dates for Kaskaskia wheat, ForagePlus oat, or Trical 2700 triticale. Overall respective concentrations of IVTD for these cultivars again were quite large, accounting for 88.6, 86.5, and 90.1% of DM. Ogle oat, which reached the most advanced growth stage on all harvest dates, exhibited declining concentrations of IVTD across harvest dates that were explained by linear ($P < 0.001$) and quadratic ($P < 0.001$) effects. The quadratic response can be explained by a 15.2-percentage unit decline between the September 19 (90.5%) and October 10 (75.3%) harvest dates, but only a marginal change (2.4 percentage units) by the end of the experiment (72.9%). This response is consistent with estimates of TDN for this forage, which declined from 67.2 to 59.2% over the same time period, with most of this depression

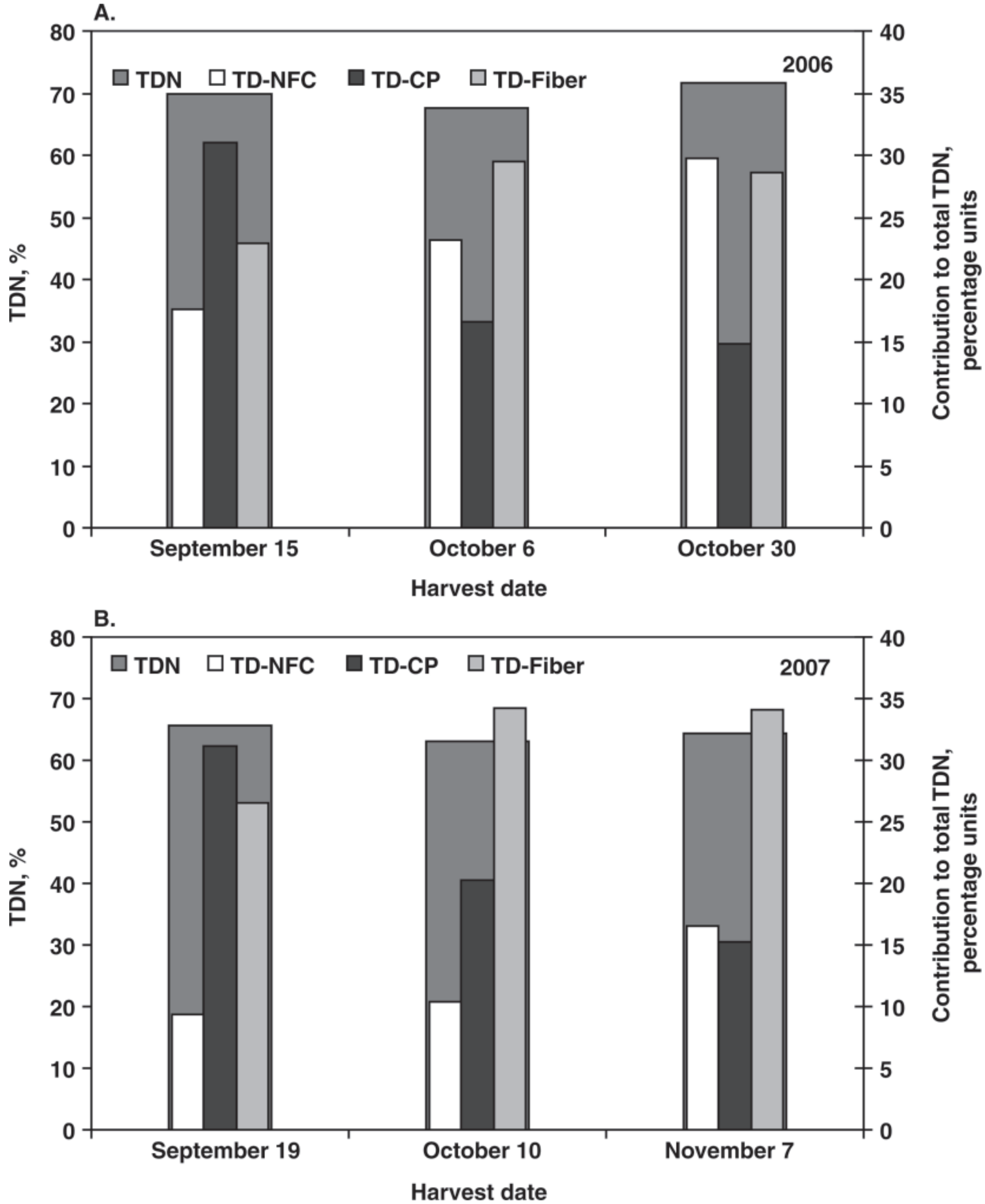

Figure 3. Concentrations of TDN for ForagePlus oat (Wisconsin Foundation Seeds, Madison) established in early August and harvested at approximately 3-wk intervals during 2006 (panel A) and 2007 (panel B). For 2006, harvest date exhibited a quadratic ($P = 0.001$) effect on concentrations of total TDN. For 2007, no effects ($P \geq 0.370$) were observed. The main components of total TDN, including truly digestible nonfiber carbohydrate (TD-NFC), truly digestible CP (TD-CP), and truly digestible fiber (TD-Fiber), are shown within each estimate of TDN; these components are scaled to the secondary y-axis for visual clarity. The SEM associated with each estimate of TDN was 0.72 and 1.72% for 2006 and 2007, respectively. Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

occurring between the initial 2 harvest dates (Table 8).

DISCUSSION

DM Yield

Over 2 yr, several important yield trends can be identified. Maximum yields of DM from oat cultivars during 2007 ranged from 5,664 to 6,650 kg/ha and were similar to those reported for oat established in early August in southern Wisconsin (≥6.7 Mg/ha; Contreras-Govea and Albrecht, 2006). However, during the less favorable growing conditions of 2006, maximum yields from oat cultivars (2,580 to 3,967 kg/ha) fell substantially short of this yield threshold. Regardless of year, fall forage production from cereal-grain forages was optimized in central Wisconsin by planting cultivars that demonstrated some stem elongation before winterkill in late fall. During both production years, elongating cultivars continued to accumulate DM throughout

October, although the accumulation rate during late October slowed to approximately one-half that exhibited during late September and early October. Oat and triticale cultivars collectively enjoyed nearly a 2 to 1 yield advantage over wheat cultivars on the final harvest dates each year; this approximate relationship has been observed previously in Arkansas (Gunsaulis et al., 2008), as well as Wisconsin (Maloney et al., 1999). In our experiment, it is interesting that this relationship was quite stable across 2 experimental years that varied widely in precipitation and October temperature. Actual yield ratios of all elongating cultivars compared with vegetative winter wheat were 1.9 and 1.8 to 1 for 2006 and 2007, respectively. For oat cultivars alone, it was identical over both years at 2.0 to 1.

Grain-type oat cultivars consistently demonstrated statistically significant yield advantages over forage-type oat cultivars by the final harvest date each fall, but these advantages were not necessarily observed on earlier dates. Previously, Chapko et al. (1991) reported that tall, late-maturing oat cultivars provided greater yields of DM when established in the spring. However,

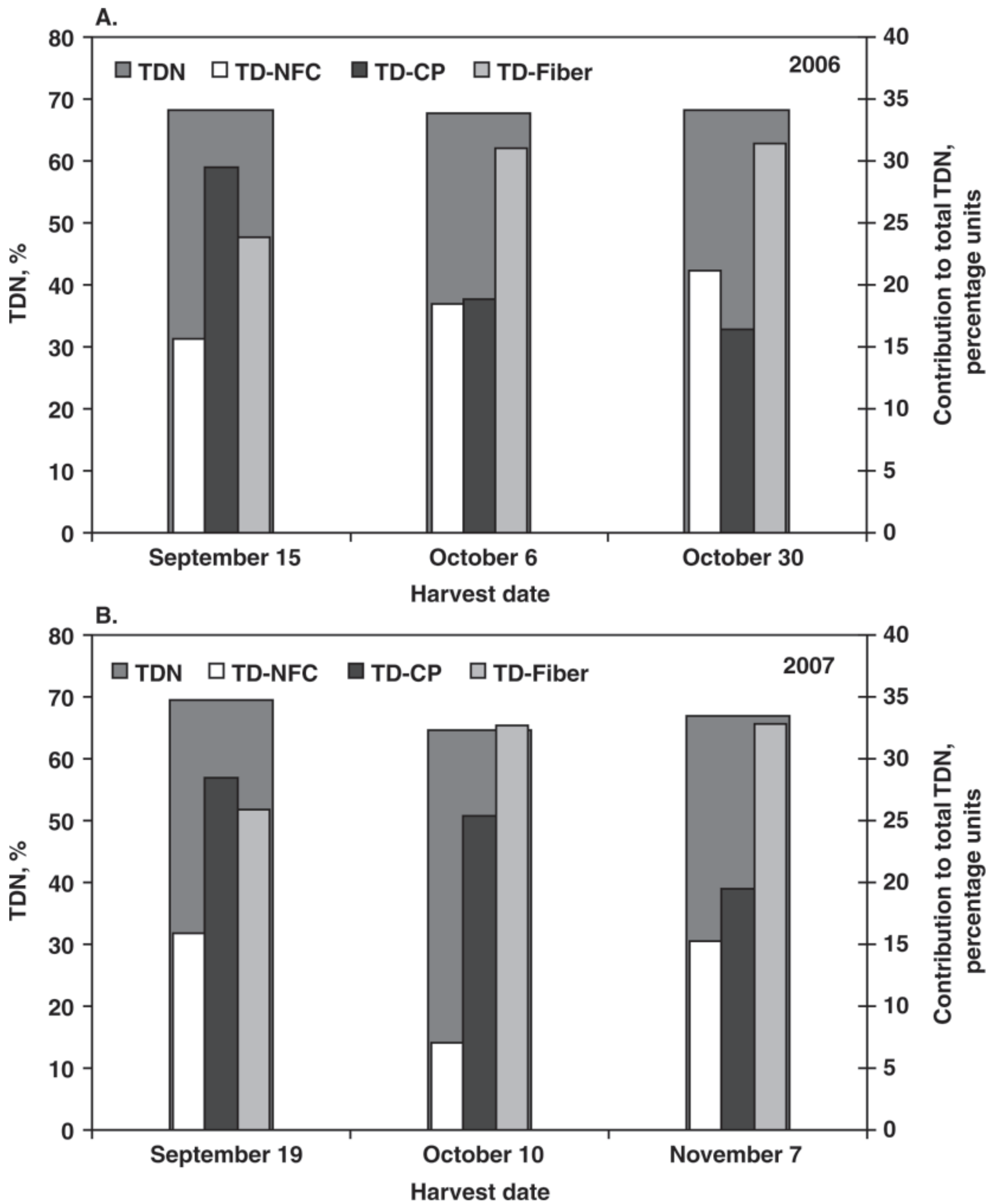

Figure 4. Concentrations of TDN for Trical 2700 triticale (Wolf River Valley Seeds, White Lake, WI) established in early August and harvested at approximately 3-wk intervals during 2006 (panel A) and 2007 (panel B). For 2006 and 2007, harvest date did not affect concentrations of TDN ($P \geq 0.072$). The main components of total TDN, including truly digestible nonfiber carbohydrate (TD-NFC), truly digestible CP (TD-CP), and truly digestible fiber (TD-Fiber), are shown within each estimate of TDN; these components are scaled to the secondary y-axis for visual clarity. The SEM associated with each estimate of TDN was 0.72 and 1.72% for 2006 and 2007, respectively. Concentrations of TDN were calculated for each forage sample from the summative equation (Weiss et al., 1992; NRC, 2001) using the ADL option for estimating truly digestible fiber.

Maloney et al. (1999) demonstrated that this relationship was inverted with August establishment because tillers had only limited time to develop; therefore, maximum fall yields were obtained from cultivars typically exhibiting early maturities after normal spring establishment. Our results consistently supported this premise and suggest that late-maturing forage-type oat cultivars, such as ForagePlus, do not produce optimum yields when established in early August. Furthermore, this trend also was observed within the 3 grain-type oat cultivars. Harvest dates for Ogle typically have occurred 3 to 4 d ahead of those for Drumlin and Vista within variety trials in Wisconsin that are timed to a common late-boot/early heading growth stage, rather than a specific calendar date (Mochon et al., 2008). Although the magnitude of the yield advantage for Ogle varied across years, and harvest dates within years, Ogle exhibited numerical yield advantages over the other 2 grain-type cultivars on 5 of 6 harvest dates throughout the experiment. Furthermore, these differentials were statistically significant on October 6 and 30, 2006, as well as October 10, 2007.

Nutritive Value

Generally, the mid-September harvest date coincided approximately with jointing for oat and triticale cultivars; therefore, the period immediately after the first harvest was one characterized by stem elongation, rapid upright growth, and aggressive accumulation of DM. Although wheat cultivars did not joint, they also exhibited upright growth and increased forage mass during this time interval. During spring, concentrations of NDF increase rapidly as cereal grains undergo stem elongation and heading (Cherney and Marten, 1982a,b; Coblentz et al., 2000, 2002); therefore, our results for fall-grown oat and triticale are consistent in this respect with expectations for harvests after conventional spring establishment.

The most unique aspect of our results is the relatively static nature of NDF concentrations during late October of each year. Frequently, spring-harvested cereal grains also exhibit static concentrations of NDF as seeds fill following flowering (Cherney and Marten, 1982a; Cherney et al., 1983; Coblentz et al., 2000); this trait has been explained on the basis of dilution of forage fiber as plants partition nonfibrous DM (primarily carbohydrate) into the filling grain head (Cherney and Marten, 1982b; Coblentz et al., 2000). For the fall harvests within our experiment, relatively stable concentrations of NDF were observed for all cultivars between the second and third harvest dates; however, this response could not be associated with grain fill, which did not occur for any cultivar. In addition, this characteristic cannot be associated with a cessation of growth because all cultivars continued to accumulate forage mass, and oat and triticale cultivars exhibited increased numbers of palpable nodes or visible seed heads between the final 2 harvest dates.

Although grain fill did not contribute to the static concentrations of NDF for all cultivars during late fall, accumulation of nonstructural carbohydrates may still explain part of this desirable effect. Previously, Contreras-Govea and Albrecht (2006) reported greater concentrations of water-soluble carbohydrates within leaf and stem tissues of fall-grown oat cultivars compared with traditional spring-planted oat. Furthermore, these differences were substantial; mean concentrations of water-soluble carbohydrates within leaf and stem tissues were 10.3 and 22.1%, respectively, compared with only 6.4 and 6.7% for these tissues after spring establishment. Winter cereal grains are known to harden at temperatures just above freezing; under these low temperature/slow growth conditions, various solutes may accumulate, including sugars, but tolerance to freezing also is assumed to be dependent on other factors, such as growth stage (Eastin and Sullivan, 1984). Theoretically, this physiological response to cold temperatures also may aid silage fermentation of fall-harvested oat forage by providing an abundance of fermentable carbohydrate (Contreras-Govea and Albrecht, 2006).

A second factor contributing to the excellent quality characteristics of oat and triticale cultivars during late fall was the likely suppression of physiological development by several factors, including colder temperatures and the long-day photoperiod requirement for flowering by oat (Dennis, 1984). Suppression of maturity for fall-grown oat cultivars has been demonstrated previously (Contreras-Govea and Albrecht, 2006); maturities for 3 oat cultivars harvested 77 d after an early August planting date ranged from late stem elongation to the heading stage of growth, whereas the same cultivars harvested after a similar growing interval in the spring were more advanced physiologically and ranged narrowly from the early to late milk stage of grain development. Previously, kinetic parameters associated with ruminal NDF degradation for oat forages have been related closely to growth stage described on a linear scale, and these regressions have exhibited consistently high coefficients of determination (r^2 or $R^2 \geq 0.837$; Coblentz et al., 2000). Furthermore, lignification of plant cell walls is exacerbated by elevated temperatures (Van Soest, 1982), and the decreased temperatures incurred by fall-grown cereal-grain forages likely limits concentrations of ADL relative to spring-grown cereal grains. Cherney et al. (1983) reported ratios of ADL to NDF ranging from 0.074 to 0.106 for spring oats harvested 7 to 28 d postheading; similarly, ratios ranging as great as 0.080 have been reported for sod-seeded oat in Arkansas (Coblentz et al., 2000). In contrast, our mean ratios of ADL to NDF averaged across all cultivars on the final harvest dates of 2006 and 2007 were far less (0.013 and 0.037, respectively), and ratios for individual cultivars ranged from 0.007 to 0.059. These reduced concentrations of ADL may improve fiber digestibility compared with spring-grown cereal forages, as well as improve TDN calculated by the summative model (Weiss et al., 1992; NRC, 2001).

Generally, selection of cereal-grain cultivars, such as oat, that exhibit stem elongation or heading after fall establishment will deliver a 2 to 1 advantage in yields of DM over wheat cultivars that remain vegetative. Fall yield can be improved further by selecting grain-type oat cultivars that typically exhibit the earliest heading dates when established traditionally in the spring. Forage-type oat cultivars that consistently out-yield grain types following spring establishment often mature slowly, and their fall growth may be limited by cold temperatures. Additional advantages of selecting elongating cultivars for fall production include relatively high concentrations of TDN and stable quality characteristics throughout the late fall, thereby affording producers a relatively broad window of opportunity for a single harvest as silage. Within this context, harvest decisions could then be based on factors such as maximization of yield, suitability of weather, or simple convenience, rather than rigid dependence on the growth stage of the forage plant. For the dairy industry, a one-time harvest as oat silage could be utilized routinely, or as an emergency measure after summer drought. However, there would be essentially no regrowth after such a harvest, nor would oat be expected to survive the winter. Within a grazing context, selection of elongating cultivars generally will provide yield advantages, regardless of grazing date, but these advantages must be weighed against poor potential for regrowth during the fall, and a near certainty of subsequent winterkill. Generally, the occurrence of winterkill may or may not be viewed as problematic, depending on producer goals, but cultivars that are likely to winterkill should be selected in response to specific producer objectives, such as providing emergency forage to graze, or to harvest as silage after summer drought. Without specific objectives, cultivars that remain vegetative during the fall may be a better choice because of their high probability of winter survival and decreased associated input costs because spring reestablishment is not required.

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